DOCUMENT RESUME

ED 443 722 SE 063 955

AUTHOR Tao, Ping-Kee
TITLE Developing Understanding through Confronting Varying Views: The Case of Solving Qualitative Physics Problems.
PUB DATE 2000-00-00
NOTE 19p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (New Orleans, LA, April 28-May 1, 2000).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cooperative Learning; *Discussion (Teaching Technique); Foreign Countries; High Schools; *Physics; *Problem Solving; Science Education
IDENTIFIERS Hong Kong

ABSTRACT

This study explored high school students' collaborative efforts in solving qualitative physics problems. It aimed to investigate whether and how confronting students with varying views help to improve their problem solving skills and develop better understanding of the underlying physics concepts. The varying views were provided to 18 grade 12 students by requiring them (a) to work in dyads on the problems during which they had to consider and confront each other's ideas; and (b) to consider, in a feedback session, multiple solutions to each problem, comparing the solutions with their own and reflecting on their mistakes. The study adopted F. Marton's theory of the structure of awareness as its theoretical underpinning--that is, the varying views would bring to the students' focal awareness, and thus enable them to discern, the different critical aspects of the problem situations. This would help them to develop conceptual understanding. The results show that confronting students with varying views can have three positive effects: (a) it enhanced students' understanding and improved their problem solving skill; (b) it induced students to reflect not only on the object of learning but also spontaneously to consider their approach to learning physics; and (c) it enabled students to see things differently and to consider, and possibly adopt, a new approach to learning physics. Importantly, the findings lend support to Marton's emerging theory. The paper ends with a discussion of the shortcomings and the educational implications of the study. (Contains 24 references.) (Author/YDS)

Reproductions supplied by EDRS are the best that can be made
from the original document.

ED 443 722

Paper Presented at

2000 Annual Meeting of
American Educational Research Association

New Orleans, LA, USA
April 24-28, 2000.

Developing understanding through confronting varying views: The case of solving qualitative physics problems

Ping-Kee Tao
Department of Curriculum Studies, The University of Hong Kong,
Pokfulam Road, Hong Kong
Email: pktao@hkucc.hku.hk

ABSTRACT

This study explored high school students' collaborative efforts in solving qualitative physics problems. It aims to investigate whether and how confronting students with varying views help to improve their problem solving skills and develop better understanding of the underlying physics concepts. The varying views were provided to 18 grade 12 students by requiring them (a) to work in dyads on the problems during which they had to consider and confront each other's ideas; and (b) to consider, in a feedback session, multiple solutions to each problem, comparing the solutions with their own and reflecting on their mistakes. The study adopts Marton's theory of the structure of awareness as its theoretical underpinning — that is, the varying views would bring to the students' focal awareness, and thus enable them to discern, the different critical aspects of the problem situations and this would help them to develop conceptual understanding. The results show that confronting students with varying views can have three positive effects: (a) it enhances students' understanding and improved their problem solving skill; (b) it induces students to reflect not only on the object of learning but also spontaneously to consider their approach to learning physics; (c) it enables students to see things differently and to consider, and possibly adopt, a new approach to learning physics. Importantly, the findings lend support to Marton's emerging theory. The paper ends with a discussion of the shortcomings and the educational implications of the study.

P. Tao

U.S. DEPARTMENT OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

SE 063 955

BEST COPY AVAILABLE

Developing understanding through confronting varying views: The case of solving qualitative physics problems

Introduction

This paper reports a study of high school students' peer collaboration in solving qualitative physics problems that formed part of a larger study. In the earlier study (Tao, 1999), it was found that peer collaboration provided students with experiences of co-construction and conflict that were conducive to successful problem solving. In co-construction, students complemented and built on each other's ideas to arrive at a solution, whilst in conflict situations they disagreed with each other as regards the problem solving strategy and/or the solution, and thus had to consider and confront each other's ideas. The early study showed that most of the conflicts occurring at the outset were followed by co-construction when the students subsequently came to agreement. However, the study found that whereas co-construction could lead to correct as well as wrong solutions, conflicts (followed by co-construction) nearly always led to correct solutions. Thus in peer collaboration it appears to be more beneficial to have students confronting each other's ideas at the outset than to have them merely building on each other's ideas.

It is therefore of interest to investigate whether confronting students with varying views would help them to improve problem solving skills and develop better understanding of the underlying physics concepts and principles. The present study sought to do this by arranging students (a) to work in dyads on qualitative physics problems (as in the earlier study) during which they had to consider and perhaps confront each other's ideas, and (b) to consider, in a feedback session, multiple solutions to each problem, comparing the solutions with their own and reflecting on their mistakes. The multiple solutions were not "model solutions" but were taken verbatim from the few successful students in the earlier study. The purpose was to subject students to more varying views of successful problem solving.

Individual and social perspectives of learning

The earlier study on collaborative physics problem solving (Tao, 1999) draws on studies on peer interactions in collaborative learning (Damon & Phelps, 1989; Mercer, 1996; Mason, 1998) which are based on Piaget's and Vygotsky's work as theoretical underpinnings. It subscribes to the view that science learning has both an individual and a social perspective (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Leach & Scott, 1999). According to Piaget (1985), the benefit of peer collaboration lies in the cognitive conflicts created from students' divergent views. The disequilibration thus engendered demands resolution and this requires students to articulate their ideas to others and to individually reflect on their understanding. Thus Piaget focuses on the individual perspective of learning treating peer collaboration (social perspective) as merely providing a useful context or vehicle for students' personal sense-making and knowledge construction.

On the other hand, Vygotsky (1978) stresses both the individual and social perspectives of learning. He regards learning as a social process in which meaning-making and understanding are first rehearsed between people before they are developed within the individual in a process of internalization. He speaks of an "interpyschological plane" and an "intrapyschological plane" of higher mental functioning and argues that any higher mental function is external before it is internal:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first *between* people (*interpyschological*), and then *inside* the child (*intrapyschological*) (p.57).

Thus, according to Vygotsky, the individual perspective of learning is derived from the social perspective. Vygotsky (1962) also contends that language plays a vital role on both the inter- and intrapyschological planes. In formal science learning, for example, mediated by cultural artifacts language provides the means for scientific ideas to be talked through between teacher and students and between students on the interpyschological plane. Internalization is the process by which students appropriate and become able to use for themselves (on the intrapyschological plane) the conceptual tools encountered on the interpyschological plane. Following internalization, language provides the tool for individual thinking. Thus language and thought are inextricably intertwined.

Crook (1994) identifies conflict and co-construction in peer interactions as two important cognitive benefits of peer collaboration. Conflicts can be traced to the Piagetian perspective of learning and co-construction to the Vygotskian perspective (Tao & Gunstone, 1999). The earlier study on collaborative physics problem solving (Tao, 1999) interpreted and analyzed peer interactions during conflicts and co-constructions to investigate how students develop shared understanding and arrived at the solutions. Such analytical framework appeared to be adequate for the purpose of the earlier study. However, for the present study, it does not seem to be particularly useful for explaining why in peer collaboration conflict would be more beneficial than co-construction, except that confronting students with varying views would provide them with more frequent and intense cognitive conflicts. One approach forward is to adopt a more fine-grained analysis of peer interactions as in, for example, Wegerif et al. (1999) and Kumpulainen and Mutanen (1999), but since such approach is based on basically the same framework, it is unlikely to shed more light on the problem. After a literature search and careful consideration, carried out after the present study had commenced, it was decided to adopt an alternative analytical framework for the present study — phenomenography (Marton, 1981, 1988) and the emerging theory of awareness (Marton & Booth, 1997; Marton,1998; Bowden & Marton, 1998).

The phenomenographic approach

Phenomenography is a research specialization developed by Marton and his colleagues over the past two decades at Goteborg University in Sweden (Marton, 1981, 1988). It is a study of how people experience, understand, conceptualize and make sense of various phenomena or aspects of the world around them. It takes up an epistemological stance that regards human understanding or conception as a human-world relation rather than the outcome of some kind of general cognitive functioning of the individual. Its research endeavors are directed at identifying and describing people's experiences of various phenomena. Such descriptions of experiences are content-oriented. They are not seen as qualities of the individuals but rather as concrete cases of human functioning (Marton, 1981). Over the years, Marton and his colleagues have examined a wide variety of phenomena covering various content domains (from economic to science topics) as well as students' conceptions of learning. In all cases, they have identified a limited number of "qualitatively different ways" of experiencing a given phenomenon. These qualitatively different ways of relating to the phenomena capture the critical differences of understandings from different viewpoints.

The structure of awareness

For many years, phenomenography has been concerned with addressing the question "What are the different ways of experiencing a phenomenon?" As such, it is basically descriptive

and methodologically oriented. In recent years, the research paradigm has shifted its emphasis to theoretical concerns. Marton and Booth (1997) recently advanced a theory concerning the structure of human awareness to address the question "What is a way of experiencing a phenomenon?" They argue that this can be described in terms of how people's awareness is structured. They characterize awareness as consisting of a generalized *figure-ground* structure: in experiencing a phenomenon, certain aspects come to the fore, become figural and thematized, whilst other aspects recede to the ground or margin and remain tacit. Therefore, to experience a phenomenon in a certain way, there is always a discernment of the whole from the context. Furthermore, a figure is composed of its constituent parts and each part contributes to the overall meaning of the figure. This involves the delimitation of the parts and their relationship within the whole.

Thus, according to Marton and Booth, in experiencing a phenomenon, certain aspects of the phenomenon are brought to our focal awareness simultaneously and become discerned. They illustrate this with the understanding of Archimedes' principle:

> Being focally aware of the weight of a body immersed in some fluid as compared to its weight when not immersed, of the fact that a certain volume of the fluid is displaced by the act of immersion, of the weight of the fluid displaced — all at the same time — amounts to what it takes to discover, or to understand, Archimedes' principle (p.101)

These authors argue that discernment depends on variation. They contend that without variability, many of the conceptions that we now use would be meaningless (for example, gender would not exist if there were only one!). When certain aspects of a phenomenon vary while other aspects remain invariant, then those aspects that vary will be brought to focal awareness. Thus to understand a way of experiencing a phenomenon, discernment, simultaneity and variation are seen as fundamental to this theory.

Quoting the work of Ueno, Arimoto and Fujita (1990), Marton and Booth argue that the fundamental difference between Newtonian and the commonsensical (Aristotelian) view of motion lies in the former discerning the frame of reference as a dimension of potential variation whilst in the latter, being-at-rest is the taken-for-granted frame of reference. They suggest that introducing the variation in perspectives (frames of reference) would facilitate the understanding of Newtonian motion. Thus they contend that learning arises from the experience of variation, which enables certain critical aspects to be brought to focal awareness simultaneously. They speak of variation as "a necessary condition for effective discernment" and as the "chief mechanism of learning". They illustrate this argument further with examples taken from studies on understanding numbers, reading text, using group as the vehicle of variation, and Nobel prizewinners' views of scientific intuition. In all cases, learning was enhanced by the experience of variation.

Marton's notion of the experience of variation is appealing as an analytical framework for explaining why in collaborative physics problem solving conflicts may be more beneficial than co-construction, a difficulty that the earlier study (Tao, 1999) failed to grapple. In conflicts, students confront each other with alternative suggestions as regards the physics principles and/or the strategies to be applied in problem solving. In so doing, the various critical aspects of the problem situation are brought to their focal awareness and become discerned and this would, as Marton and Booth (1997) argue, facilitate learning. The present study contrives situations to intensify the dimension of variations by not only setting students to work collaboratively on qualitative physics problems but also provide, in a feedback session, variations in solution to each problem for students to consider and reflect upon. The study aims to investigate whether variation

helps student to improve their problem solving skills and develop better understanding of the underlying physics concepts and principles. As such, it attempts to provide support for Marton and Booth's theory of awareness.

Methods

Subjects

A Secondary 6 (grade 12) physics class with 18 students in a Hong Kong school took part in the study. In Hong Kong, only about one-third of the students completing Secondary 5 (grade 11) are offered subsidized places in pre-university course in Secondary 6 and 7 based on their results in the Hong Kong Certificate of Education Examination (HKCEE). Secondary 6/7 students are therefore generally well motivated and committed to their study. The subjects in this study, basically a convenient sample, were of average ability – their mean HKCEE physics grade was about C (on a scale of A to E).

The study was carried out in four stages: pre-test, feedback, post-test, and interview. In the first two stages, pre-test and feedback, students were arranged to work in dyads during which their peer interactions were audio-recorded. As far as possible, students of opposite sex were randomly assigned to each dyad so that in transcribing the audio-tapes they could readily be differentiated from their voices. The third and fourth stages of the study involved administering a post-test, and conducting interviews with individual students.

The four stages of the study and the comparison between the pre- and post-test are described below.

Pre-test

The pre-test, given in Figure 1, consisted of three qualitative physics problems from the earlier study (Tao, 1999). The three problems are conceptual in nature and involved curved mirror, trolley-mass system and electric circuit respectively. They are qualitative in the sense that no numerical values are given and no calculation or set procedure is required. To solve the problems students need to interpret and understand the problem situation qualitatively and to apply relevant basic physics principles. These problems tested physics principles covered in Secondary 5 but differed markedly from the quantitative physics problems that students encountered in textbooks and examinations. Such quantitative problems usually require the routine application of formulae and equations for solution.

The test was administered to the class in a 40-minute lesson. Prior to the test, the researcher briefly explained that the problems in the test were qualitative in nature and that students were to work together in dyads to solve them. No specific training in collaborative skills was provided; the students were simply asked to engage in discussion to arrive at a joint solution. While students worked on the problems their peer interactions were audio-recorded.

The pre-test was marked by the researcher according to the marking scheme from the earlier study, with 1 mark given to each correct solution and 0 mark to wrong solution. Four randomly selected scripts were marked by a research assistant. There was agreement between the researcher and the research assistant in all but one problem in one script.

Feedback

A feedback session was arranged one week after the pre-test. Students were returned their marked scripts and given a solution sheet with which to compare their own solutions. The solution sheet offered more and explicit variations by providing two to four different solutions to each problem.

For example, for problem 3, as shown in Figure 2, the dimensions of variation were problem solving strategies based on (a) the current through, (b) the voltage across, and (c) the power dissipated in the lamps in the circuit. The solutions were not "model solutions" but were taken verbatim from the few successful students in the earlier study.

Despite the plea to give qualitative solutions, some students in the present (and the earlier) study adopted a quantitative approach – they transformed the problems into mathematical form by assigning symbols to given quantities and set up equations to solve the unknown. Solution 3 to problem 3 in Figure 2 is one such quantitative solution. The quantitative solutions were scored as correct if there was no mistake in the derivation and interpretation of the answer.

Students considered the solutions in dyads and their collaborative exchanges were again audio-recorded. They were asked to write down their views on each solution, compare and contrast it with their own, and to reflect on the mistakes they made.

Post-test

Three and half months after the feedback session, a post-test consisting of three *parallel* problems was administered to the class. The post-test was endorsed by a panel of three experienced physics teachers who agreed that the problems were parallel to those in the pre-test, that is, they were similar in format and structure and required the application of the same physics principles and strategies for solution. As an illustration, problem 3 is given in Figure 3. Students took the test individually. Students' scripts were marked by the researcher and the marking was checked in the same way as in the pre-test. There was no teaching on the topics tested during the intervening period.

Interview

Semi-structured individual interviews were conducted by the researcher's assistant with each student two weeks after the post-test. Students were asked what they thought of the whole process and whether and what they had learned from it and in which stage. They were also asked about their views on qualitative physics problems and peer collaboration.

Comparison of the pre- and post-test

The level of difficulty of the pre- and post-test was compared by administering the two tests to a Secondary 6 class (36 students) in another school. The mean HKCE physics grade of this class was C, same as that of the class in the main study. This class was divided into two halves to which students were randomly assigned such that there was no significant difference between them in (a) the mean HKCEE physics grade in Secondary 5, and (b) the school physics examination mean score in Secondary 6. The pre-test was administered to one half of the class and the post-test to the other half. The results showed that there was no significant difference between the overall performance the two half-classes. Thus it cannot be argued that any improvement in performance from pre- to post-test of the students in the main study was due to easier problems in the post-test.

Results

Data on 8 out of 9 dyads in the class were analyzed. Dyad 1 had to be excluded because one of the students was absent from the post-test. In the following, the students in each dyad are referred to as A and B and student A of dyad 1, for example, is referred to as student 1A.

Pre-test

Table 1 gives the performance of each dyad in the pre-test (and of individual students in the post-test). The dyads performed rather poorly in the pre-test. Of the 24 responses (3 problems x 8 dyads), only 6 were correct. The 6 correct solutions came from 3 dyads: dyad 3 was correct in all three problems, dyad 2 correct in problems 1 and 2, and dyad 7 correct in problem 1 only. The qualitative physics problems, which were unfamiliar to the students, had presented considerable difficulties to them. Students' common errors were:

P1 Rather than drawing the reflected rays by applying the laws of reflection (such that the angle of incidence is equal to the angle of reflection), 5 dyads attempted in vain to use the construction rules (rays along specific directions) to complete the ray diagram.

P2 5 dyads argued that since the table surface and the pulley were smooth, $F = mg$. They were not aware that mg accelerated both the block and the trolley whilst F, being the tension of the string, accelerated the trolley only.

P3 6 dyads answered correctly that when lamp Z was disconnected lamp Y became brighter, but they maintained that lamp X remained unchanged rather than dimmer. They were not aware that disconnecting lamp Z from the circuit affected not only the parallel branches of lamps Y and Z but also the entire circuit.

Despite the poor performance on the test, the rich qualitative data of collaborative exchanges showed that students engaged intensively in the problem solving tasks and readily made public their own ideas and freely discussed each other's, irrespective of whether their joint solutions were correct or not.

While working on their own in dyads on the problems, the students were confronted with two dimensions of variation: variation in problem solving strategies and variation in understandings of the underlying physics concepts/principles. Some examples from the successful students are given below.

Variation in problem solving strategies. In problem 1 (curved mirror), the two students in dyad 3 came up with two different problem solving strategies: Student A suggested using the laws of reflection and student B the construction rules.

A: This is a mirror, not a lens, just like those mirrors ... the rays will be reflected. I think it should be like this (drawing the rays), but it seems not correct, ah ... no.
B: But this [ray] doesn't pass through the focus [meaning not a construction rule]. If it passes through the focus, it will be reflected in this way.
A: The angles should be the same. Suppose this is the incident angle. If this [the incident angle] is 30 degrees, this [the reflected angle] is also 30 degrees, like this. ... (drawing the rays). Then the point [from which the reflected rays appear to diverge] is here, isn't it?
B: Isn't it?

Student A elaborated further on the position of the point from which the reflected appeared to diverge.

A: If [the ray] is incident like this, the reflected angle is the same as the incident angle, and then ... this is a mirror... so, like this ... behind [the mirror] ... So, the rays are reflected here, then [the point is] inside, nearer [to the mirror]. It's about here, it should be nearer, I think.

Later, after finishing the other two problems, the two students returned to the problem again. Student B was still uncertain if the laws of reflection could be applied to a convex mirror.

Student A explained to student B how to draw the normal to the curved mirror from which the incident and reflected angles could be worked out.

B: This is a convex mirror … If this were a normal [plane] mirror, I think it'd be OK.
A: No, if this is a curved line, curved like this, the ray is incident like this and a perpendicular line, the normal, is drawn here, and it's [the ray is] still reflected in this way [same reflected angle]… suppose this is a tangent, a tangent to this curve, the incident angle is 30 degrees and then this reflected angle. Just like this …… (drawing the diagram) … same [angle] θ.

The above shows that initially the laws of reflection was in student A's focal awareness whereas the construction rules was in student B's. During the exchanges, the two students each made explicit and public his/her ideas to the other student for scrutiny and evaluation. In the process, they became aware of both ideas simultaneously and subsequently one student was persuaded to give up her problem solving strategy and accept the other's.

Variation in understanding. In solving problem 2 (trolley-mass system), after some preliminary discussion dyad 3 proposed that $F = mg$. They rehearsed their arguments as follows.

A: So, F must be equal to mg if there is no friction. It's because the tension, the tension of the string can be treated as mg, isn't it?
B: The string is of negligible mass.
A: Yes.
B: The pulley has no friction.
A: mg.
B: The surface also has no friction.
A: The tension …
B: The tension of this mass should be equal to mg.

These exchanges show that the properties of the trolley-mass system (string of negligible mass, frictionless pulley and bench surface) was in the students' focal awareness. This explains why they contended that $F = mg$. However, further discussion led student A to suddenly realise that if $F = mg$, the mass would not fall, at which point in time student B also realized that F was the tension of the string, not equal to mg.

A: It may not be … if so, it [the mass] won't fall… mg won't fall.
B: Actually, is the tension equal to this force [F]?
A: Yes. The tension is equal to F. But is the tension equal to mg? … I don't remember … I think so.
B: Fall …
A: The tension is equal to mg …
B: If the tension is equal to mg, it [the mass] won't fall.
A: Oh, yes.
B: So, mg is greater than the tension.
A: Yes, yes … mg is greater than the tension. Then F is smaller than, smaller than mg … I think so.
B: F is smaller than mg.
A: The trolley is moving … Is the trolley moving? [It's] accelerating, accelerating. That means the tension is smaller than mg. If not, the mass won't fall.
B: So, the force is smaller than mg.

These exchanges show that students' focal awareness had shifted from the properties of the system to the motion, in particular the acceleration, of the system. They invoked Newton's second law (that acceleration was due to a net force acting on a system) and gave a correct solution to the problem, $F < mg$. During the exchanges the two students complemented and built

or each other's ideas. It is conjectured that without the mutual support and the confrontation of each other's ideas, they individually would not have been able to shift their focal awareness.

Peer collaboration leading to wrong solution. In solving problem 3 (electric circuit), dyad 7 had no difficulty with working out the equivalent resistance of the circuit before and after lamp Z was disconnected. They understood that the brightness of a lamp was proportional to the voltage across it and deduced that lamp Y became brighter. However, it did not occur to them that the removal of lamp Z affected not only the parallel combination of lamps Y and Z but also the entire circuit including lamp X. They contended that the brightness of X remained unchanged.

A: Let's find the R [resistance]. This R is equal to ...
B: This?
A: This is equal to R over 2 [½R] . Less voltage is across them [Y and Z in parallel]. Then more [voltage] is across this, more voltage is across [lamp] X. Less [voltage] is across this parallel [circuit], half R
B: This [lamp Z] is disconnected.
A: It's like this at first. When this [Z] is not here, [the lamps] are in series.
B: Yes.
A: If in series, this [X] is as bright as this [Y]. This [The brightness of Y] is increased and this [X] remains unchanged.
B: Yes. If Z is connected, Y and Z are less bright. X is brighter. Oh, I remember.

The two students went on to write down their solution during which they rehearsed their arguments again. However, the effect of the removal of lamp Z on the entire circuit had again not been brought to their focal awareness. They concluded incorrectly that "lamp X unchanged, lamp Y becomes brighter."

Feedback

By its design, the feedback session forced students to consider the multiple solutions to the problems and, in the process, to ponder over the critical aspects of the physics concepts and principles utilized in each solution. In general, the majority of the students, working in dyads, underwent extensive reflection during the session. The reflection focused on two aspects: the variation of the solutions and metacognition (students' awareness of the mistakes they made and their approaches to learning).

Variation of solutions. The majority of the dyads compared and contrasted the different given solutions and commented on their efficacy. Some dyads identified their own correct solutions from amongst the given ones. For example, dyad 3 who gave a correct solution to problem 3 (electric circuit) commented that solution 1 based on voltage was simpler than solution 2 based on current which they used. Student 3A said that he had forgotten about the formula for power in solution 3, but student 3B claimed that actually she could recall the formula but found it too troublesome to do the calculation. This shows that dyad 3 was well aware of the critical aspects of the physics concepts and principles manifested in each solution.

In going through the solution sheet, many dyads verbalized the given solutions during which they became aware of some critical aspects that they had overlooked. For example, dyad 7, who gave a wrong solution to problem 3 (electric circuit) that lamp X's brightness remained unchanged, had the following collaborative exchanges:

B: Oh I see. The resistance of Y is 1 over R before Z is disconnected. Then this is the total resistance. As V is unchanged, after Z is disconnected, I [the current] is smaller because the total resistance is 2R which is higher. Then, let me see. Then as V [the voltage] is unchanged and R [the resistance]

is increased from 3/2 R to 2R, I is smaller. Then X receives smaller current as it's [the resistance of X] R before Z is disconnected, let me see, no …

A: That's right.

B: At first, Z's …

A: Because they're [Y and Z] in parallel at first, … that means the total resistance is increased. [The current through] X is decreased relatively.

B: Oh, I see. I understand it now.

Through verbalizing and discussing the solutions, this dyad became aware that any change in one part of the circuit affected not only the resistance of that part but also the resistance of the entire circuit.

One of the dyads (dyad 2) not only verbalized the given solutions but also rewrote the solutions to each problem in their own words on the solution sheet.

Metacognition. Some dyads went beyond reflecting on the content of the solution. For example, dyad 8 was very explicit about the mistakes that they made in the pre-test, as the following exchanges show:

A: Yes, I was wrong. The voltage, no, the resistance of the whole system is higher [when lamp Z is disconnected] and X's resistance is unchanged. So it draws a lower voltage. We didn't realize that the total resistance is higher, not only Y's resistance is higher. We were wrong there.

B: This problem requires us to think about the effects of the combination of a series and a parallel circuit on the voltage and resistance. If our concepts were clearer, we wouldn't have made such a mistake.

Some dyads went further to reflect on their approach to learning physics. After going through the solution sheet, one student, 2B, had a spontaneous discussion with another student in a neighboring dyad on his approach to learning physics. The following were some of the remarks student 2B made during the discussion:

> We should apply the principles flexibly. We shouldn't rely on the formulae and should use our own words. … These problems inspire us very much. … May be we didn't think deeply, just like in the past.

One dyad (dyad 8) reflected at length on their approach to learning physics spontaneously after finishing the solution sheet. They lamented that the drill and practice of problem solving was unhelpful or even detrimental to their understanding of physics, as shown by the following exchanges:

B: … But the concept is rarely applied in the actual calculations or even can't be applied. It's OK just to memorize the formulae and diagrams. But actually when we need to solve these qualitative problems, these basic principles are very useful. The basic principles are neglected in the beginning and time is spent mostly on calculations, so it [the test] was not done well.

A: How to say? The biggest problem is not that students don't know the basic principles. Actually, they knew most of them, I think. But as time passes, as they do more past exam papers and MC questions they begin to think about quick methods, quick methods to solve problems and to get good grades, and they become confused about the concepts.

Student B concurred that excessive drill and practice had turned them into 'scoring machine' and caused 'confusion' in their understanding of physics. He admitted that he did not like physics because it involved too many calculations.

> B: … If we think more of concepts, this may be better, particularly for students like us, we'll be more interested [in the subject]. I find physics hard because there are too many calculations.

They ended their lengthy discussion by resolving that they would "reflect more on the basic principles, not focusing on the formulae", and "not be a scoring machine".

Post-test

As shown in Table 1, students' performances improved considerably in the post-test. Of the 24 responses, 16 were correct for either one or both students in the dyads compared with 6 correct responses in the pre-test. There were 6, 6 and 4 correct responses for Problems 1, 2 and 3 respectively in the post-test for either or both students in the dyads compared with 3, 2 and 1 correct responses in the pre-test. Considering the level of difficulty of the problems and the fact that there was a time span of three and half months between the feedback and the post-test, the students' improvement in performance at the post-test was quite remarkable.

The post-test was planned as an individual test in an attempt to find out whether students internalized the understandings that they developed while working in dyads. However, as it turned out the data collected, plus those from the interviews, did not shed much light on students' process of internalization, hence the shift of the study's analytical framework to the theory of awareness. The earlier study (Tao, 1999) found that students in collaboration performed better in solving the problems than students working alone. Thus if students had attempted the post-test in dyads, they would have performed even better.

Interview

At the interview, the majority of students claimed that they had learned much from the process and that they were positive towards qualitative physics problems and peer collaboration. In general, students who performed well at the post-test were more articulate in their responses than those who performed poorly. Three students, however, displayed negative views.

Students' perceived learning. Many students claimed that they had learned much from the process, attributing it to the qualitative nature of the problems and the multiple solutions. Many students were able to recall details of the different solutions provided.

For example, student 7B, claimed that she learned much from the variations in the solutions and the different viewpoint of her partner, as the following excerpt shows:

> I saw different solutions for the same problem, … there were two different perspectives of thinking. When two persons discuss together, I think of one idea and the other person thinks of another and the two ideas would combine. If working alone, there's only one idea. When reading the solutions, I learned there are other methods.

Student 8B also highly commended the usefulness of the multiple solutions to the problems:

> I think the feedback session was the best because different solutions were shown to us and [then we know] there are many different methods. I learn to think of the problems in different ways, not just do the calculations as taught in school. … Many creative answers were given in that solution

sheet. Like what I said before, they're not the model answers, but can suggest different methods to you and can guide you to think in different perspectives.

Student 7A, one of the best performing students, could recall the mistakes that he made:

I learn the basic concept in physics, like those in mechanics [Question 2]. I got them wrong before. After that, I was clear about the concepts, like *mg*, force, and tension. Then optics [Question 1], nothing in particular [his solution at pre-test was correct]. Electricity, light bulbs [Question 3], I got this wrong before, like the increase of the brightness, now I know. And we can exchange ideas during collaboration.

Qualitative physics problems. Many students claimed that the qualitative physics problems had helped them to develop a new approach to learning physics, as the following excerpts show:

I've learned how to think in physics, not just memorize, but think step by step, how [to do] in this step and how in the next step. For example, someone can memorize the rules about the mirror, [the rays] are incident like this and reflected like this. But those problems we did weren't like that, [they] can't be found in the textbook. They require us to analyze how [the rays are] reflected when they're incident in this direction. There are a few rules in the textbook but they didn't appear in that problem. (Student 3B)

It really tested very basic concepts. It really tested your understanding of physics, not how you substitute the given formulae. … I learned how to deal with physics, how to think. (Student 4A)

Peer collaboration. The majority of students were positive about peer collaboration arguing that it had provided them with variation in viewpoints. The excerpt from student 7B quoted above is one example. Another example is from Student 2B:

It's better with collaboration. Working together is better than doing alone because discussion is possible. Yes, if we argue during the discussion we can discuss which point is better. (Student 2B)

Other students suggested that peer collaboration increased their confidence and provided them with peer support:

I was afraid at first. I was afraid when seeing those unfamiliar diagrams and didn't know where and how to start. Then when we discussed and came up with some ideas, it was good. (Student 4B)

I felt I was more confident when working with another person. He reminded me when I made mistakes and I also reminded him when he made mistakes. I felt more confident and it's more likely to be correct. (Student 7B)

Negative views. Not unexpectedly, a small minority of students (3 out of 16 students) showed negative views. Student 9A was very negative about the whole process. When asked about what he felt about the whole process, he lamented:

The whole process? … Just finish all the things and that's all. We skipped a few lessons. Yeah, no special feeling.

When asked about whether he had learned anything, he showed an examination-oriented approach to learning in his response:

> The problems are outside the syllabus. Like problem 1 [convex mirror], it doesn't follow the syllabus to apply the construction rules.

In fact the problems are well within the syllabus, only that they are not the types usually set in examinations.

Student 5A was skeptical about peer collaboration. He preferred direct teaching to peer collaboration arguing that it was more cost-effective:

> It took much time and it was not effective. May be it's better if it's taught directly. ... I did learn something, but how about the amount? Is it better if the same amount of time is used for teaching other things? ... Actually, it's more effective when the teacher teaches than when two persons discuss with each other.

The two students, 9A and 5A, both failed to solve any of the problems in the pre- and post-test.

Another student, 8B, was also negative about peer collaboration, but for another reason. He claimed that he had learned much from the multiple solutions (see excerpt above) but he preferred working alone to collaborating with another student. He contended that he was deprived of the opportunity to 'think thoroughly' when working with a more able partner.

> I think it was bad because much time was spent on arguing. There was not enough time to think thoroughly. Because I didn't have a good grade in physics, I followed what he said if what he insisted seemed correct. Many times I neglected the things that I should think of. I just wrote down what he said if he insisted that.

Student 8B was not disposed towards collaborative learning. He also failed to solve any of the problems in both the pre- and post-test.

Conclusion and discussion

The results show that confronting students with varying views has three positive effects on students:

1. It enhances students' understanding and improves their problem solving skills as shown by students' improvement in performance from pre- to post-test.
2. It can induce students to reflect not only on the objects of learning (physics principles and problem-solving strategies) but also spontaneously to consider their approach to learning physics.
3. It enables students to see things differently – particularly that there can be several problem-solving strategies for the same physics problem and that there are other ways to learn physics.

There have been very few studies on Marton and Booth's theory of awareness. One recent study (Pong, 1999, 2000) in economic education which investigated students' conceptions of price and trade across a range of contexts found that many students changed their conceptions as they moved from one context to another (*inter-contextual shifts*) as well as within a specific context (*intra-contextual shifts*). The data suggest that the contextual shifts were strongly influenced by which critical aspects of the context that were in students' focal awareness at the time. Thus there is a close relationship between context, focus and meaning. Pong concludes his study by suggesting that to foster learning school instruction should strive to provide variations for students' understanding. Whilst Pong's study considers the dynamics of awareness, the present study explores the issue of variation directly. Confronting students with varying views did

enable them to discern a number of critical aspects of the problem situation, and this helped them to develop conceptual understanding, as well as new insights into what it means to learn physics -- a metacognitive development.

Admittedly, the findings of the study cannot be claimed to be entirely conclusive. There was a shift in the analytical framework half-way through the study and some of the research procedures did not fully take account of the newly adopted framework. For example, the study could have been carried out using a treatment/control design and students could have been set to do the post-test in dyads as in the pre-test rather than individually. This points to further work. Nevertheless, the rich qualitative data collected, in particular those from the peer interactions and interviews, do shed some light on how the dimensions of variations help to facilitate students learning.

The findings of the study have important implications for physics teaching and learning. The strategy of providing multiple solutions to physics problems offers exciting possibility for developing students' conceptual understanding of physics. This strategy is not difficult to implement. Some of the traditional quantitative problems can readily be transformed into qualitative forms and the large body of research on students' alternative conceptions is a useful resource for such problems (Pfundt & Duit, 1994). Multiple solutions can also be generated by students themselves working on the qualitative problems, as was the case in the present study. In mathematics problem solving, the consideration and generation of multiple solutions has long been regarded as important and is a subject of active interest (Silver, Leung, & Cai, 1995; Stigler & Hiebert, 1999), but this has not been the case in physics. The present study suggests that multiple solutions to physics problems warrant attention and further study. It also suggests that a useful theoretical underpinning for such endeavors is Marton and Booth's theory of awareness.

Acknowledgements

The research reported in this article was supported by an award of the CRCG Research Grant of the University of Hong Kong (10202058/13924/10100/301/01).

References

Bowden, J. & Marton, F. (1998). *The university of learning: Beyond quality and competence in higher education*. London: Kogan Page.

Crook, C. (1994). *Computers and the collaborative experiences of learning*. London: Routledge.

Damon, W. & Phelps, E. (1989). Critical distinction among the three approaches to peer education. *International Journal of Educational Research, 13*, 9-19.

Driver, R., Asoko, H., Leach, J., Mortimer, E. & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 13*, 3-19.

Kumpulainen, K. & Mutanen, M. (1999). The situated dynamics of peer group intraction: an introduction to an analytic framework. *Learning and Instruction, 9*, 449-473.

Leech, J. & Scott, P. (1999, August). Teaching and learning science: Linking individual and sociocultural perspectives. Paper presented at the European Conference for Learning and Instruction, Goteborg, Sweden.

Marton, F. (1981). Phenomenography – describing conceptions of the world around us. *Instructional Science, 10*, 177-200.

Marton, F. (1988). Describing and improving learning. In R.R. Schmeck (Ed.) *Learning strategies and learning styles* (pp.53-82). New York: Plenum Press.

Marton, F. (1998). Towards a theory of quality in higher education. In B. Dart & G. Boulton-Lewis (Eds.), *Teaching and Learning in Higher Education* (pp.177-200). Melbourne: ACER.

Marton, F. & Booth, S. (1997). *Learning and awareness*. Mahwah, NJ: Lawrence Erlbaum Associates.

Mason, L. (1998). Sharing cognition to construct scientific knowledge in school context: The role of oral and written discourse. *Instructional Science, 26*, 359-389.

Mercer, N. (1996). The quality of talk in children's collaborative activity in the classroom. *Learning and Instruction, 6* (4), 359-377.

Pfundt, H. & Duit, R. (1994) *Bibliography: Students' alternative frameworks and science education* 4th edition. Kiel: IPN.

Piaget, J. (1985). *The equilibration of cognitive structure*. Chicago: Chicago University Press.

Pong (1999, August). The dynamics of awareness. Paper presented at the European Conference for Learning and Instruction, Goteborg, Sweden.

Pong (2000). Widening the space of variation -- inter-contextual and intra-contextual shifts in pupils' understanding of two economic concepts. Unpublished Ph.D. thesis, University of Hong Kong.

Silver, E. A., Leung, S. S. & Cai, J. (1995). Generating multiple solutions for a problem: A comparison of the responses of US and Japanese students. *Educational Studies of Mathematics, 28* (1), 35-54.

Stigler, J.W. & Hiebert, J. (1999). The teaching gap. New York: Free Press.

Tao, P.K. & Gunstone, R.F. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education, 21* (1), 39-57.

Tao, P.K. (1999). Peer collaboration in solving qualitative physics problems: The role of collaborative talk. *Research in Science Education*. 29 (3), 365-383.

Ueno, N., Arimoto, N. & Fujita, G. (1990, April). Conceptual models and points of view: Learning via making a new stage. Paper presented at the annual meeting of AERA, Boston.

Vygotsky, L.S. (1962). *Thought and language*. Cambridge, M.A.: MIT Press.

Vygotsky, L.S. (1978). Mind in society: The development of higher psychological processes. Cambridge, M.A.: Harvard University Press.

Wegerif, R., Mercer, N. & Dawes, L. (1999). From social interaction to individual reasoning: an empirical investigation of a possible socio-cultural model of cognitive development. *Learning and Instruction, 9*, 493-516.

Table 1 Performance of dyads in pre-test and of individual students in post-test

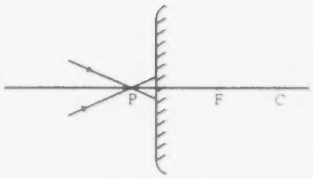
Dyad^	Student	HKCEE Physics grade	Pre-test*				Post-test*			
			P1#	P2	P3	Total	P1	P2	P3	Total
2	A	C	0	0	0	0	0	1	0	1
	B	C					0	0	0	0
3	A	C	1	1	1	3	1	1	0	2
	B	C					1	1	1	3
4	A	B	1	1	0	2	1	1	0	2
	B	C					1	0	1	2
5	A	C	0	0	0	0	0	0	0	0
	B	C					1	0	0	1
6	A	C	0	0	0	0	0	1	0	1
	B	C					1	0	0	1
7	A	B	1	0	0	1	1	1	1	3
	B	C					1	0	0	1
8	A	B	0	0	0	0	1	0	0	1
	B	D					0	0	0	0
9	A	B	0	0	0	0	0	0	0	0
	B	C					0	1	1	2

* Students completed pre-test in dyads and post-test individually

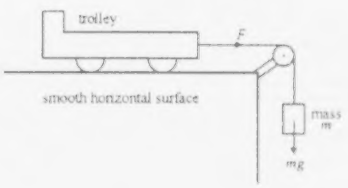
1 = correct solution; 0 = wrong solution

^ Data from dyad 1 excluded from analysis (student A absent from post-test)

P1. A beam of light converges to a point P just in front of a convex mirror. Complete the ray diagram and find the approximate position of the point to which the reflected rays converge or appear to diverge from. Explain your answer briefly.



P2. A mass m is used to accelerate a trolley along a horizontal frictionless table as shown. Assume that the pulley is smooth and that the string is of negligible mass. How does the force F accelerating the trolley compare with the weight mg of the mass? Answer by stating whether $F = mg$, $F < mg$ or $F > mg$. Explain your answer briefly.



P3. Three identical lamps, X, Y and Z, are connected up in a circuit as shown below. What happens to the brightness of lamps X and Y when lamp Z is unscrewed (i.e. disconnected)? Answer by stating whether the brightness increases, decreases or remains unchanged. Explain your answer briefly.

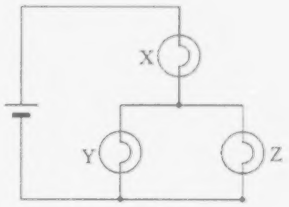


Figure 1 Qualitative physics problems in the pre-test

Solution 1

Y, Z in parallel,
Equivalent resistance < Y's resistance
When Z is unscrewed,
Voltage across Y increases, and
Voltage across X decreases
⇒ Brightness of X decrease
⇒ Brightness of Y increase

Solution 2

Resistance of lamp = R
Z not disconnected:
Total resistance

$$R_T = R + \frac{1}{1/R + 1/R}$$

$= R + \frac{1}{2}R = 1\frac{1}{2}R$
Z disconnected:
$R_T = R + R = 2R$
$V = IR$
V remains unchanged
$R \uparrow \Rightarrow I \downarrow$
X receive smaller current
⇒ X decreases in brightness
Y receive larger current
⇒ Y increases in brightness

Solution 3

Let R = resistance of lamp bulb
Before Z is unscrewed, $R_{total} = 1.5\ R$
$I_X = V/1.5R$, P of $X = (V/1.5R)^2 R$
I_Y or $I_Z = V/3R$,
P of Y or $Z = (V/3R)^2 R$
After Z is unscrewed,
$R_{total} = 2\ R$
$I = V/2R$
P_X or $P_Y = (V/2R)^2 R$
P_X after < P_X before
P_Y after > P_Y before
⇒ X decreases, Y increases

Figure 2 Multiple solutions to Problem 3 (electric circuit) in pre-test

P3. Two identical lamps, X and Y, and a variable resistor R are connected up in a circuit as shown below. At first, R is adjusted such that its resistance is the same as that of lamp Y. The resistance of R is then increased. What happens to the brightness of lamps X and Y?
Answer by stating whether the brightness increases, decreases or remains unchanged.
Explain your answer briefly.

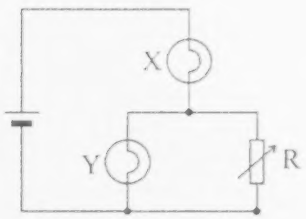


Figure 3 Problem 3 in post-test

BEST COPY AVAILABLE